International Journal of Plastic and
Polymer Technology (IJPPT)
ISSN(P): 2249-6904; ISSN(E): 2249-801X
Vol. 7, Issue 1, Jun 2018, 1- 8

A REVIEW ON MODIFICATIONS AND HYBRIDIZATION IN SYNTACTIC FOAM

AMOL NANDKUMAR PATIL[1] & PRAVIN R. KUBADE[2]

[1]*Post Graduate Student, Department of Production Engineering, K. I. T.'s College of Engineering, Kolhapur, Maharashtra, India*

[2]*Assistant Professor, Department of Production Engineering, K. I. T.'s College of Engineering, Kolhapur, Maharashtra, India*

ABSTRACT

Syntactic foams are the materials synthesized by using pre-fabricated hollow microspheres which are commonly made of glass, ceramic, polymer or metal and bounded with a polymer. Syntactic foam has unique properties of high strength at low density thus these become widely used in subsea buoyancy applications. For several applications like marine, automotive and aerospace, syntactic foams are used as energy absorption sandwich core. The current study is focused to take a look of the work done in the area of characterization of Syntactic Foam composite materials and various modifications in synthetic foam. This study is attempt to take overview of different constituent materials used to make polymer composites, failure mechanism and manufacturing process of Syntactic Foam composite material. The behavior of such hybrid syntactic foam under tensile loading, compression loading, flexural loading and impact loading are the main areas of interest of researchers. This paper reviews work related to syntactic foam fabricated by using following two types of micro balloons that are hollow glass microspheres and fly ash cenospheres.

KEYWORD: Syntactic Foam, Polymer Matrix, Glass Microballoons & Fly Ash Cenosphere

Received: Jan 04, 2018; **Accepted:** Jan 25, 2018; **Published:** Feb 05, 2018; **Paper Id.:** IJPPTJUN20181

Original Article

INTRODUCTION

Composites

The main advantages of composite materials are high strength, modulus, bending stiffness, chemical resistance and low moisture uptake etc. Properties of composites can be tailored according to specific design requirements, directional and spatial properties of constituents. In recent days nano reinforcements are also used to enhance the thermal and mechanical properties of composites.[23]At the present composite materials have found wide spread applications in marine, aeronautics, automobiles and space sector due to their lightweight and high strength.

Syntactic Foams

Syntactic Foams were developed in the 1960s as buoyancy aid materials for deep-sea applications. [15] The "syntactic" portion refers to the ordered structure provided by the hollow spheres. The "foam" term relates to the cellular nature of the material. Syntactic materials are sturdy enough to with stand the effect of hydrostatic pressure and long lasting exposure to water thus these are ideal for oceaneering tasks such as cable and hardball floats and instrumentation support. Presently they are used in aircraft, spacecraft and ship structures. [16] Syntactic foams are porous composite materials synthesized by filling a matrix material (metal, polymer, or ceramic) with hollow particles called microballoons. Fillers i.e. microballoons are used to lower the amount of more expensive matrix materials and/or to enhance or tailor some properties of matrix materials. Typical examples of micro-balloons are hollow glass microspheres, fly ash cenospheres, polymeric micro-balloons, carbon microballoons, metal oxides, etc. [17] Hollow glass microsphere are highly engineered basically comprising of silica and alumina, and possess good properties such as

high specific strength, regularity of their surface, good wetting characteristics, low viscosity of the resin-microballoons mixture, energy absorption properties, low cost, ease of fabrication. Fly ash cenospheres are lightweight, idle, and empty circles comprising of silica and alumina, are loaded with air or gasses, and possess characteristics such as high specific strength, irregularity of their surface, average-wetting characteristics, energy absorption properties, very low cost thus showing good values to replace conventional fillers and thereby lowering composite cost and reducing land pollution. [18] Syntactic foams are known for their high specific compressive strength, low moisture absorption and excellent damping properties, higher thermal and chemical stability, high damage tolerance and ability to keep damage localized. These are used as core materials in sandwich composites for weight sensitive structural applications, thermal insulation and conduction, sport equipment's, body armor, etc. Syntactic foams are multi-functional composite materials due to their broad range of mechanical properties coupled with vibration damping characteristics, fire performance and ability to be fabricated in functionally graded Configurations. [19] For Syntactic Foam composite materials, it is observed that extensive work has been done related to characterization of various syntactic foams . Most of studies in a literature on polymer matrix syntactic foam composites was largely done on thermo set polymers such as epoxy, vinyl ester, cyanate ester, phenolic resins and thermoplastic polymers such as polyethylene, polystyrene resin system and fillers such as hollow glass microsphere, cenosphere, phenolic/carbon microballoons. Some studies incorporated nano-clay, carbon nano Fiber, carbon nano tube as nano reinforcing materials, while some used glass and aramid fibers as micro reinforcement, whereas studies carried to attempt hybridize two different material microballoons at time are limited. Typical examples of micro balloons are hollow glass microspheres, fly ash cenospheres, polymeric micro-balloons, carbon micro balloons, etc. Figure 1shows the two phase and three-phase structure of the syntactic foam.

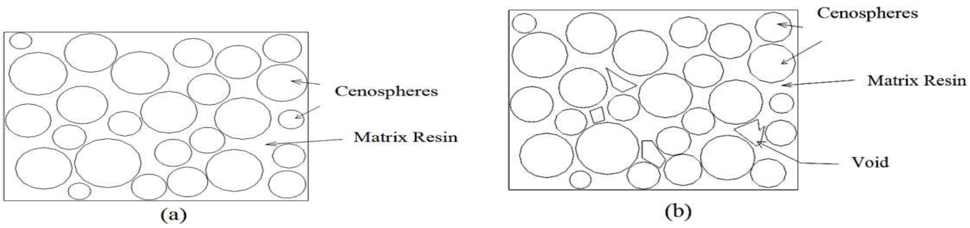

Figure 1: (a) Two Phase (b) Three Phase Structure of Syntactic Foam[19]

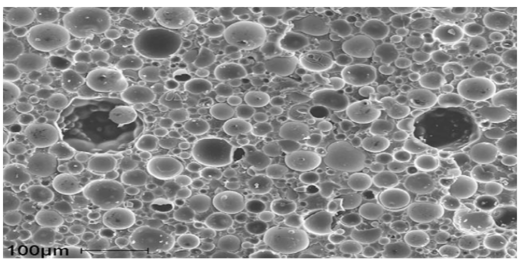

Figure 2: Vinyl Ester Matrix Syntactic Foam [18]

EXISTING RESEARCH EFFORTS

Labella et al. (2014) reported that elastic energy absorption of fly ash cenosphere reinforced vinyl ester syntactic foam was higher in high strain rate compression than quasi -static compression. They observed that compressive strength was decreased by 12-19% and modulus was increased by 50-70% in quasi-static compression than the neat vinyl resin. They reported deceased flexural strength and increased flexural modulus with increased vol. % and at 60 vol.% it was high as 73% and 47%, respectively ascribed to cenospheres stress concentration in materials and also defects in cenospheres.

The coefficient of thermal expansion decreased with increased vol. % of fly ash cenospheres. [1]

Ghamsari et al. (2014) developed Bucky epoxy matrix syntactic foam utilizing imidazolium base ionic liquid (IL, wt. filler% =0.5, 1, 7.5, 15) for dispersing single walled carbon nano tube (CNT, wt. filler% = 0.25, 1, 2). They reported degradation of yield strength, elastic modulus and energy absorption in compression loading at high CNT and IL content however at low content of CNT (0.25 wt.%) and IL (0.5 wt.%), improvement in mechanical properties was noticed. They reported marginal increase in electrical conductivity by addition of CNT and IL hybrid gel. They also reported contradicting effects on mechanical and electrical properties. [2]

Colloca et al. (2013) reported 10-47% increase and 8-15% decrease in tensile strength and modulus in 50 vol.% and 30 vol.% of glass microballoon reinforced epoxy syntactic foams, respectively with addition of carbon nano fiber in range of 0.30 to 0.42 vol.%. [3]

Zhang and Ma (2013) investigated the effect of carbon nano-fiber (CNF, Φ filler%=0.5, 1.0, 1.5, 2.0) addition on the compressive, flexural and fracture toughness properties of the hollow carbon microspheres (const. Φ filler%=28)/ phenolic resin syntactic foam. They observed that no significant improvement in compressive strength is observed with addition of CNFs as crushing of microsphere was the main failure mechanism, while flexural strength and fracture toughness improved considerably with addition of CNFs up to 1.5 vol.% after which it was decreased attributed to agglomeration and clustering of CNFs. They reported crack deflection, microsphere debonding, microsphere crushing and deformation, step structure (CNF pull-out with debonding from matrix) as the failure mechanism. [4]

Desai et al (2014) investigated an effect of surface modification (3-methacryloxy propyl trimethoxysilane coupling agent) of cenospheres (wt. filler% = 10, 15, 20, 25, 30)/ acrylonitrile butadiene styrene (ABS) matrix SFs on thermal, electrical, fire retardancy [5] and dynamic mechanical [6] properties. SFs were manufactured by PIM. They reported low heat deflection temperature (HDT) i.e. distortion temperature in treated cenospheres to that of untreated cenosphere SFs at a given concentration and it was increased with addition of both type of cenosphere. Glass transition temperature and decomposition temperature was nearly same as of ABS matrix thus thermal stability detected. They found 20 wt. % cenosphere as critical fraction up to which dielectric constant increased but above that it was decreased and it was higher for untreated cenosphere for all samples. They observed small difference between treated and untreated cenosphere and fire retardancy increases with increase in cenosphere content due to their ceramic nature. [5] In the dynamic mechanical analysis they found that addition of cenosphere increases storage modulus and simultaneously decrease loss modulus while loss factor shows fluctuating trend and highest loss factor was observed at 15 wt. % cenosphere content at room temperature. [6]

Zegeye et al. (2014) reported the influence of pristine graphene platelets (Φ filler% = 0.1, 0.3, 0.5) reinforcements on tensile and compressive properties of HGM (Φ filler% = 30)/ epoxy SFs. They reported 3.6 % and 2.4% increase in compressive strength, 15.9% and 14.7% increase in tensile strength, 4.57% and 14.70% increase in tensile modulus at 0.1% and 0.3% volume fraction of graphene platelets respectively. They found 0.3% volume fraction as critical volume fraction beyond which mechanical properties deteriorated. They also observed increase in fracture strain thus increase in toughness for all graphene reinforced foams. They relate enhancement in properties to the strong interaction between graphene platelets layer and polymer matrix which in turn restrains motion of polymer chains and thus delayed crack initiation and growth. [7]

Poveda et al. (2014) worked on the effect of carbon nano fiber (CNF, wt. filler% = 1,2) reinforcement on the visco-elastic properties (storage and loss modulus, loss factor, max. use and glass transition temperature) of HGM (ρTP = 0.22, 0.46 g/cc, Φ filler% = 30, 40) / epoxy based syntactic foam in the temperature range of-750C to 1500C. They reported maximum increase in storage modulus and loss modulus at room temperature. They observed decrease in storage modulus and increase in loss modulus at room temperature with addition of CNF to syntactic foam. Max use and glass transition temperature increased by max. of 27.1% and 25%, respectively to neat epoxy resin.[8]

Huang and Li (2015) studied an effect of HGM volume fraction on elastic behavior and fracture mechanics of epoxy syntactic foam in compression loading. They developed a FEM model with representative elementary volume for different volume fraction. They found that localized stresses can cause vertical splitting fracture of micro balloons and macro crack formation in matrix as fracture mechanisms. Also micro cracks join adjacent micro crack to form macro crack either in longitudinal direction for low volume fraction or in diagonal direction for high volume fraction. They reported increase in young's modulus and critical strain with increase in volume fraction attributed to above stated failure mechanisms. [9]

Kumar et al. (2016) worked on the effect of surface modification of cenosphere (Φ filler% = 0, 20, 40, 60)/ functionalized high-density polyethylene (HDPE) and blending methods (mechanical mixing and brabender mixer) on the tensile [10] and flexural [11] properties of polymer injection molded (PIM) SFs(SFs). They treated cenosphere with 3Aminopropyltriethoxysilane coupling agent and HDPE was functionalized with Dibutyl maleate (DBM). They reported increase in density, tensile modulus and strength with increasing treated cenosphere content. Highest strength and modulus was observed for treated cenosphere (Φ filler% = 40)/ functionalized HDPE and untreated cenosphere (Φ filler%= 60)/ virgin HDPE SFs respectively. They highlighted use of brabender mixing process over mechanical mixing as highest tensile strength and modulus was obtained in brabender mixing due to effectiveness in particle cluster braking leading to high matrix-particle surface area generation [10]. Also they reported that density, flexural strength and modulus was increased with increase in treated cenosphere content and functionalized HDPE SFs and was dependent on mixing methods. Brabender mixing yields highest strength and modulus at treated cenosphere (Φ filler% = 60)/functionalized HDPE SFs with 41% and 70% improvement than the neat HDPE. They employed Profiri-Gupta and Bardella-Genna model to predict flexural properties in which later was predicted better at high filler content. [11]

Kumar et al. (2016) worked on the strain rate sensitivity of SFs (SFs) with cenosphere (Φ filler%= 0, 20, 40, 60)/ high-density polyethylene (HDPE) blending with mechanical mixing prior to fed into polymer injection molded (PIM) machine by quasi-static (10-4/s, 10-3/s,10-2/s) and high (3430/s, 2700/s, 1810/s) strain rate compression. They reported that compressive strength and modulus increased with increasing cenosphere content than the neat HDPE at same quas-static strain rate and average strength at high strain rate is 2-fold of the strength at quasi-static strain rate for same cenosphere content thus strain rate sensitive. [12]

Kumar et al. (2016) worked on the tensile characterization of Cenosphere (true particle density: 0.8 g/cc, vol. %: 0, 20, 40, 60)/ high density polyethylene (HDPE) matrix syntactic foam produced by optimized polymer injection mouldings (PIM) machine. Tensile test showed relatively brittle failure with only a little plastic deformation. They observed matrix as main crack propagation carrier while defects in cenosphere, non-spherical shape and poor particle-matrix adhesion also contributed in failure mechanisms. Theoretical modeling was used to estimate the properties of cenosphere. [13]

Q. Tian and D. Yu (2016) worked on the effect of interfacial adhesion between hollow/ solid poly (divinylbenzene-co-glycidyl methacrylate(P[DVB-GMA]) polymer microsphere/epoxy matrix on the tensile, electrical and optical properties of syntactic foam. they created hollow and solid polymer microspheres/epoxy composite films via powder mixing method and UV-curable polymerization and interfacial adhesion was established by chemical bonding among the epoxy groups of the microspheres and epoxy matrix. They reported higher tensile strength and modulus for hollow polymer microsphere to that of solid microsphere syntactic foam, also there was increase in tensile strength and modulus with increase in filler content to critical limit and then decreased which was attributed to shift in failure mechanism from shear yielding deformation, particle bridging and crack blowing to the particle debonding. They reported slight decrease in electrical resistivity and UV transmittance with hollow microsphere content increased. [14]

DISCUSSIONS

After reviewing the existing literature available on syntactic foams, it has been found that most of researchers used different resin systems and studied structural relations for synthetic foam. Mechanical properties of synthetic foam in different resin systems are different and also depend upon the hardeners used, curing cycle and fabrication method used. Some researchers studied syntactic foam fabricated using different types of microballoons such as hollow glass microsphere, cenosphere, phenolic/carbon microballoons, etc. some researchers added reinforcement such as carbon nano Fiber, Carbon nano Tube, glass and aramid fibers as micro reinforcement. Addition of carbon nano tube (CNT) fillers improves mechanical properties and electrical conductivity. Improvement in tensile strength is observed by reinforcement of carbon nano fiber in epoxy syntactic foam. Flexural strength and fracture toughness is improved considerably with addition of carbon nano fibers (CNF) up to 1.5 vol.% . Reinforcement of pristine graphene platelets reinforcements increases compressive strength and increase in tensile strength. Visco-elastic properties may get altered by addition of carbon nano fiber. Injection molded fly-ash cenosphere syntactic foam shows increase in density, tensile strength and flexural strength. There are very few researchers who attempted to hybrid two different material microballoons at time. Studies about hybridization of two different material microballoons are limited.

SUMMARY

The above studies in a literature on polymer matrix syntactic foam composites was largely done on thermoset polymers such as epoxy, vinyl ester, cyanate ester, phenolic resins and thermoplastic polymers such as polyethylene, polystyrene resin system and fillers such as hollow glass microsphere, cenosphere, phenolic/carbon microballoons. In addition few researchers have used modified polymer resin systems. Very few researchers did surface modification of microballoons. Few studies incorporated nano-clay, carbon nano Fiber, carbon nano tube as nano reinforcing materials, while some used glass and aramid fibers as micro reinforcement. Most studies have compared their results to previous studies done by other researchers, which used different resin-hardener systems, curing cycles, manufacturing methods, etc., which affect obtained results. There are very few researchers who attempted to hybrid two or more different material microballoons at time. There are various different types of microballoons such as glass microballoons, phenolic microballoons, alumilite microballoons, ceramic microballoons and metallic hollow microspheres which has different characteristics.

CONCLUSIONS

There is scope for hybridization of two types of microballoons to study deformation and fracture behavior of such

composite in various loading conditions. Increased interest of transportation structures in the lightweight composites has built considerable interest in exploring new methods to enhance the properties of syntactic foams. In hybrid syntactic foam, two different types of microballoons have different properties and surface structures can build up different deformation and fracture behavior. As this syntactic foams might be used as sandwich core in variety of weight sensitive applications makes it necessary to understand and predict the deformation and fracture behavior of such reinforced syntactic foams.

REFERENCES

1. *Labella M., ZeltmannS. E., ShunmugasamyV. C., Gupta N. and RohatgiP. K., "Mechanical and thermal properties of fly ash/vinyl ester syntactic foams," Fuel, vol. 121, pp. 240-249, 2014.*
2. *Ghamsari A. K., Wicker S. and WoldesenbetE., "Bucky syntacticfoam; multi-functional composite utilizing carbon nanotubes-ionic liquid hybrid," Composites Part B: Engineering, vol. 67, pp. 1-8, 2014*
3. *Colloca M., Gupta N. and PorfiriM., "Tensile properties of carbon nanofiber reinforced multiscale syntactic foams," Composites Part B: Engineering, vol. 44, pp. 584-591, 2013*
4. *Zhang L. and Ma J., "Effect of carbon nanofiber reinforcement on mechanical properties of syntactic foam," Materials Science & Engineering, vol. A, no. 574, pp. 191-196, 2013*
5. *Desai J. R., Shit S. C. and Jain S. K., "Studies on thermal, electrical and flame properties of surface modified cenosphere filled ABS composites," International Journal of Plastic Technology, 2014.*
6. *Desai J. R., Shit S. C. and Jain S. K. Jain, "Analysis of 3-methacryloxypropyl trimethoxysilane treated cenosphere inclusion on dynamic mechanical properties of ABS composites," International Journal of Plastic Technology, 2016.*
7. *Kumaraswamy H S, Venkatesh M K & Bharath V G, Characterization of Pultruded Fiber Reinforced High Performance Polymer Matrix Composite with Carbon Nano Tubes, International Journal of Metallurgical & Materials Science and Engineering (IJMMSE), Volume 4, Issue 1, January - February 2014, pp. 1-8*
8. *ZegeyeE., Ghamsari A. K. and WoldesenbetE., "Mechanical properties of grapheneplatelets reinforced syntactic foams," Composites Part B: Engineering, vol. 60, pp. 268-273, 2014.*
9. *P. N. E. Naveen & R. V. Prasad, Evaluation of Mechanical Properties of Coconut Coir/Bamboo Fiber Reinforced Polymer Matrix Composites, International Journal of Metallurgical & Materials Science and Engineering (IJMMSE), Volume 3, Issue 4, September - October 2013, pp. 15-22*
10. *PovedaR. L., AcharS. and Gupta N., "Viscoelastic properties of carbon nanofiber reinforced multiscale syntactic foam," Composites Part B: Engineering, vol. 58, pp. 208-216, 2014.*
11. *Huang R. and Li P., "Elastic behaviour and failure mechanism in epoxy syntactic foams: The effect of glass microballoon volume fractions," Composites Part B: Engineering, vol. 78, pp. 401-408, 2015.*
12. *Kumar B. R. B., ZeltmannS. E., MrityunjayD., Gupta N., UzmaS. G. and RaoR. N. S., "Effect of cenosphere surface treatment and blending method on the tensile properties of thermoplastic matrix syntactic foams," Journal of Applied Polymer Science, 2016.*
13. *Kumar B. R. B., ZeltmannS. E., MrityunjayD., Gupta N., UzmaS. G. and RaoR. N. S., "Effect of particle surface treatment and blending method on flexural properties of injection-molded cenosphere/HDPE syntactic foams," Journal of Materials Science, 2016.*

14. *Kumar B. R. B., Singh A. K.,Doddamani M., Gupta N. and Dung D. L., "Quasi-Static and High Strain Rate Compressive Response of Injection-Molded Cenosphere/HDPE Syntactic Foam," The Journal of The Minerals, Metals \& Materials Society, 2016.*
15. *Kumar B. R. B., DoddamaniM., ZeltmannS. E., Gupta N. and Ramakrishna S., "Data characterizing tensile behavior of cenosphere/HDPE syntactic foam," Data in Brief, vol. 6, pp. 933-941, 2016.*
16. *TianQ. and Yu D., "Preparation and properties of polymer microspheres filled epoxy composite films by UV-curable polymerization," Materials \& Design, vol. 107, pp. 221-229, 2016*
17. *Kaw A. K., Mechanics of Composites Materials, second ed., london, : Taylor & Francis, 2006.*
18. *Thomas C. R., "Syntactic carbon foams," Materials Science and Engineering, vol. 12, pp. 219-233, 1973.*
19. *NaffakhM., Díez-PascualA. M., Marco C., Ellis G. J. and Gómez-FatouM. A., "Opportunities and challenges in the use of inorganic fullerene-like nanoparticles to produce advanced polymer nanocomposites," Progress in Polymer Science, vol. 38, pp. 1163-1231, 2013.*
20. *Gupta N., Ye R. and PorfiriM., "Comparison of tensile and compressive characteristics of vinyl ester/glass microballoon syntactic foams," Composites Part B: Engineering, vol. 41, pp. 236-245, 2010.*
21. *Gupta N., PinisettyD., ChakravarthyV. and Shunmugasamy, "Reinforced Polymer Matrix Syntactic Foams Effect of Nano and Micro-Scale Reinforcement", I ed., Springer, 2013.*
22. *Kumar B. R. B., DoddamaniM., ZeltmannS. E., Gupta N. and Ramakrishna S., "Data characterizing tensile behavior of cenosphere/HDPE syntactic foam," Data in Brief, vol. 6, pp. 933-941, 2016.*
23. *NjugunaJ., Ed., "Lightweight Composite Structures in Transport: Design, Manufacturing, Analysis and Performance", seventh ed., Woodhead Publishing, 2016*
24. *Gupta N. and ParamsothyM., "Metal-and Polymer-Matrix Composites: Functional Lightweight Materials for High-Performance Structures," The Journal of The Minerals, Metals \& Materials Society, vol. 66, pp. 862-865, 2014.*
25. *Kubade P. and Tambe P. "Influence of surface modification of halloysite nanotubes and its localization in PP phase on mechanical and thermal properties of PP/ABS blends." Composite interfaces 24.5 (2017): 469-487.*
26. *Kubade P. and Tambe P. "Influence of halloysite nanotubes (HNTs) on morphology, crystallization, mechanical and thermal behavior of PP/ABS blends and its composites in presence and absence of duel compatibilizer." Composite interfaces 23.5 (2016): 433-451*
27. *Saha M., Tambe P., Pal S., KubadeP., ManivasagamG., M. XaviorA.&UmashankarV., "Effect of non-ionic surfactant assisted modification of hexagonal boron nitride nanoplatelets on the mechanical and thermal properties of epoxy nanocomposites",Composite Interface vol. 22, pp. 611-627, 2015.*